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SEA ICE THICKNESS: THE GREAT INTEGRATOR

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INTRODUCTION

The extent of the sea ice cover and its thickness distribution, which combine to define sea ice volume, are the two most critical parameters controlling ocean-atmosphere energy exchange in the Arctic Ocean. Both respond quite dramatically to changes in heat and momentum of the atmosphere and ocean and, hence, are sensitive indicators of changes in the global circulation system. The thickness distribution in a given region is controlled by thermodynamic growth, ice motion (advection), and mechanical redistribution. Therefore, the ice thickness is an integrator of atmospheric and oceanic effects which may or may not work in concert to produce thickness changes of the same sign. A primary challenge in making ice thickness measurements pertinent to issues of climate change lies in appropriately addressing the high degree of spatial variability in this complex, natural system. Another significant challenge is the effective application of satellite information to detect and monitor the ice thickness from space, which is certainly the best field of view. The objective of this summary is to present background information on the techniques, both measurement and modeling, that are currently used to address the issue of sea ice thickness. With this information in hand, workshop activities will address how these techniques can be further combined, improved, and augmented to provide an effective long-term observing system for monitoring the sea ice thickness distribution.

OBSERVATIONS

Much of what we know about Arctic sea ice thickness, on the basin-wide or regional scale, has been derived from submarine-based upward-looking sonar records of ice draft. While recognizing that the number of cruises are much too small to accurately monitor changes in ice thickness, these cruises provide the best data currently available to assess potential large-scale changes. A number of papers published in the 1980's using a limited number of ice draft profiles provided a general overview of ice thickness in the Arctic Ocean. Only recently has consistent evidence of thinning been identified from the analysis of much additional data. The completely unclassified SCICEX cruises of 1993-2000, and the decision by the Navy to release formerly classified data have significantly increased the database and our knowledge of thickness in the Arctic Ocean. Ice draft data from several UK submarine cruises has been made available, as well. The National Snow and Ice Data Center currently holds data from about 20 individual submarine cruises spanning the period 1976 to 1997, all data that was originally collected digitally. An ongoing project is scanning, digitizing, and processing data from as many as 35 additional cruises collected on analog charts, which will provide reliable ice draft information from the late 1950's until present.

While the number of U.S. Navy attack submarines has been sizably reduced and the SCICEX program no longer has totally dedicated missions, submarines still visit the Arctic. The newer class of submarines, which is configured for year-round Arctic missions, no longer supports digital recording of ice draft. To insure continued high quality ice draft data, a completely independent upward-looking sonar or swathmapper, including its own recording system, should be developed. The system should have the capability of being easily installed on any submarine deployed in the Arctic. Several survey tracklines should be designated, which are optimally designed and located for investigating temporal variability. The Navy should be encourage to have submarines visit the Arctic as often as possible and, as part of their mission, travel along these designated survey tracklines.

An alternative and complementary means of measuring and monitoring ice thickness in the Arctic Ocean is moored upward-looking sonars. A sizeable number of moored upward-looking sonars have been successfully deployed in the past. The largest concentration of these instruments has been in Fram Strait and the Greenland Sea, and the associated data have provided some useful information on ice export through Fram Strait. It seems obvious that a coordinated effort to strategically locate moored sonar within the Arctic Ocean (e.g. Canada Basin, E. Siberian Sea) would provide very useful time series of ice draft and speed. Further, the impact of data from moored sonars can be significantly increased by the relatively simple effort of instituting a coordinated archival system.

Surface-based, autonomous mass balance sites offer another source of direct observations on the temporal evolution of the thickness of the sea ice cover. Recent results suggest that, when combined, data from these sites offer useful generalizations about bare ice and melt ponds. The key in effectively using surface-based mass balance sites, as with moored sonars, is location, location, location.

Ship-based surveys of the ice cover can provide direct information on ice conditions (ice type, concentration, snow depth, meltpond distribution, etc) at specific times and locations. They are especially useful for validating and extending aircraft or satellite remote sensing methods, to allow field investigations of ice properties, and for the deployment of autonomous measurement sites into the far reaches of the Arctic Basin. Ship surveys have been used for documenting ice thickness along transit routes. Ice thickness documented from shipboard surveys are usually estimates from direct visual observations or recorded image scenes, frequently visually calibrated against an object of known size extending from the side of a ship. Ice thickness measurements attained from these surveys need to be treated with some degree of caution. In heavy ice conditions, an icebreaker pilot will select the path of least resistance along the general ship heading. The chosen route frequently consists of thin ice or leads, thus a regional thickness estimate may be biased towards thinner ice. An on-board helicopter can be used to extend the ship survey area and obtain more quantitative information on ice conditions if equipped with instrumentation such as camera or laser profiler.

Aircraft-borne laser profilers provide direct measurements of the ice surface elevations. To obtain pdfs of the ice draft, a simple coordinate transform, expanding the measured surface elevations by the ratio of mean draft to mean elevation, is applied. The method is subject to very accurate measurement of ice freeboard, which requires removal of the aircraft altitude variation from the surface profile. Obtaining the proper factor for the transformation requires knowledge of snow depth and density as well as mean ice and near-surface water density. Another promising technology for obtaining surface profiles is satellite radar altimetry. More accurate radar altimeters are scheduled to be available on future satellites. In addition to improved accuracy, the satellite platform will significantly expand the spatial extent of the measurements of ice surface elevation and, hence, the information on ice thickness.

Certainly, a central ingredient for long-term and extensive monitoring of the ice thickness is the application of indirect methods, primarily satellite-based products. AVHRR and SAR imagery have been used to provide information on the relatively thin end of the ice thickness distribution scale. These systems work most effectively when it is cold. The SAR imagery is analyzed using the RADARSAT Geophysical Processor System (RGPS). The thickness of relatively thin ice is estimated by tracking the opening and closing of ice within a defined cell and applying an empirical ice growth formula. The relative amounts of first-year and multiyear ice are established by considering the distinguishing backscattering signatures of these ice type in the SAR images. As with submarine surveys, a critical question of availability looms in the immediate future, related to the fate of RADARSAT. RGPS products are derived from RADARSAT imagery and this satellite is currently scheduled to go offline in the spring of 2002.

MODELS

Models of the sea ice cover have come a long way. Consistent in the development of models is the effort to incorporate the correct physics and remove bias in model results, including the velocity field, the deformation field, and the ice thickness distribution. Both thermodynamic-dynamics models of the sea ice cover and prognostic models indicate that an accurate representation of forcing parameters, especially winds, is key to the quality of the model prediction. Ideally, once biases are removed, data assimilation can be used to improve the correlations between model results and observations. It has recently been demonstrated that the assimilation of buoy and SSMI ice velocities improves the correlation of modeled mean ice thickness with the SCICEX-derived mean ice thickness from R=0.45 to R=0.60. These same results do show that the assimilation process generates further biases, indicating that the model needs further improvement both in model physics and model forcing. Key to these improvements is the design and application of observation data sets that can be used in the development and validation of models.

Another point to consider in the continued development of models is the representation of the fundamentally important redistribution process, which is a function of the assumed ice thickness distribution theory. Traditionally, the thickness distribution theory has been centered on g(h), whereas what we can observe is h(x). The observations contain information about spatial correlations in thickness, but there is nothing in the currently assumed theory about that. So, maybe a theory in which ridging and opening are spatial random processes, and g(h) is a projection onto thickness space that happened later, would be a better fit with what we can measure. A particularly good tool for exploring and testing various redistribution techniques is the discrete element model, because it treats ridging and opening explicitly.

SUMMARY

To understand the role of the Arctic ice cover in the global circulation system and to effectively use the ice cover as an indicator of change, it is absolutely necessary to monitor the thickness of the sea ice cover. Clearly, there are a significant number of tools available and currently used for this very purpose, each with its specific set of attributes. Key to using and further developing these tools for a large-scale observing system is to effectively combine their attributes and to coordinate measurement and modeling efforts. In the course of establishing a large-scale observing system, particularly significant attention must be paid to the validation of systems and models and the identification of priority locations for instrument deployment and repeat surveys. We hope to make significant headway in designing such an observing system during the course of this workshop.